Errors in GPS due to Satellite C1-P1 Code Biases

Ron Muellerschoen
Jet Propulsion Laboratory
Pasadena CA

Edward Powers
U.S. Naval Observatory
Washington DC

New receivers (Ashtech Z-12, AOA Benchmark, AOA TurboRogues upgraded with ACT, JAVAD, etc..) in the IGS network provide direct pseudorange observables P1 and P2 without the use of Y-codes. The AOA Rogue and TurboRogue (TR), which currently comprise the core of the IGS network, use CA code and track the cross-correlated (P2-P1) pseudorange and the (L2-L1) phase differences to produce synthesized versions of P2 and L2. Their "P1" (which is actually C1) and L1 observables are formed by tracking the CA code.

The difference between C1 and P1 is not mean zero, but can be biased by up to 2 ns (60 cm.) These biases vary among the GPS satellites and are fairly stable over time. The effect of using ionosphere-free range measurments to kinematically positioning a direct tracking P1/P2 receiver with precision IGS GPS orbits and C1 clocks, without a accounting for this bias, can degrade the scatter in the vertical from 74 cm to 88 cm, and in the horizontal from 40 cm to 50 cm. However, because of the lower noise in the phase measurements, ionosphere-free phase measurements added to this kinematic positioning reduce the scatter down to 3-4 cm in the vertical and 2-3 cm in the horizontal regardless of whether this bias is accounted for. For static positioning, again phase and range measurements with and with out this bias produce the nearly identical results, with the only consequence an increase in the dual-frequency range noise from, for example, 33 cm to 37 cm.

Conversly because the GPS control segment uses GPS P code measurements to compute the broadcast GPS orbits and clocks corrections, a C1 only GPS user range error (URE) will be increased as much as a half a meter over a P1 user's due to this P1 to C1 bias.

We have monitored these bias intermittently at JPL since 1997 with a network of 14 Ashtech Z-12 receivers in real-time. At hourly increments, a new network solution of the C1-P1 bias solutions is computed, and the results averaged over several week periods to obtain the values of these biases.

Independent data analysis contributed by the United States Naval Observatory (USNO) Time Service department of data taken from an experimental JAVAD receiver operated at USNO in Washington DC and a AOA Benchmark operated at the USNO Alternate Master Clock(AMC) at Schriever AFB confirms the JPL results. This USNO data was averaged over a two week period in June 1999. The agreement with the network of ashtech Z-12 receivers is within 0.1 ns (3 cm).

Although these C1 to P1 bias are small the resulting errors are significant and will become more significant as GPS performance improves over the coming decade. Other similar bias will likely exist with the new military code relative to the P-code and C-code. These errors can be reduced or eliminated if either a correction for each bias is broadcast in the GPS message or this error can be removed with better satellite design.

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3.3.1.8 Signal Coherence. All transmitted signals for a particular SV shall be coherently derived from the same on-board frequency standard; all digital signals shall be clocked in coincidence with the PRN transitions for the P-signal and occur at the P-signal transition speed. On the L1 channel the data transitions of the two modulating signals (i.e., that containing the P(Y)-code and that containing the C/A-code) shall be such that the average time difference between the transitions does not exceed 10 nanoseconds (two sigma).

User Error Problem

- GPS control segment uses GPS P-code measurements to compute the broadcast GPS orbits and clocks corrections.
- The US Coast Guard uses P-code receivers to compute differential corrections which are broadcast as part of a differential network.
  - is only the Ashtech CA code measurement used ?

User Error Problem

- For a CA only user, using the P-code based broadcast parameters results in range error.
  - most CA users are single-freq., so their errors are dominated by ionosphere errors. (and a.s.)
- Coast Guard differential users are mostly CA-code single-freq. receivers.
  - ionosphere and a.s. may no longer be dominant error source if operating near a ref. station.

CA/P Code Bias Similar to TGD

- Single freq. user subtracts from his broadcast clock 1.545*(B2-B1)
  - a.k.a. TauGd (interfreq. bias)
- Likewise, CA-code user would subtract from his P-code based broadcast/differential clock a P-CA bias.
  - but this effects phase residuals too.
    - alternatively, add CA-P bias to CA_range data only.

Comparison: TGD & CA/P bias

prn	centered TGD (m)	centered CA-P (m)
1	0.305	-0.056
2	0.864	-0.300
13	-2.347	0.537
15	0.584	-0.329
22	0.026	-0.432
26	-0.672	0.420
31	-0.533	-0.177
rms:	0.77	0.29

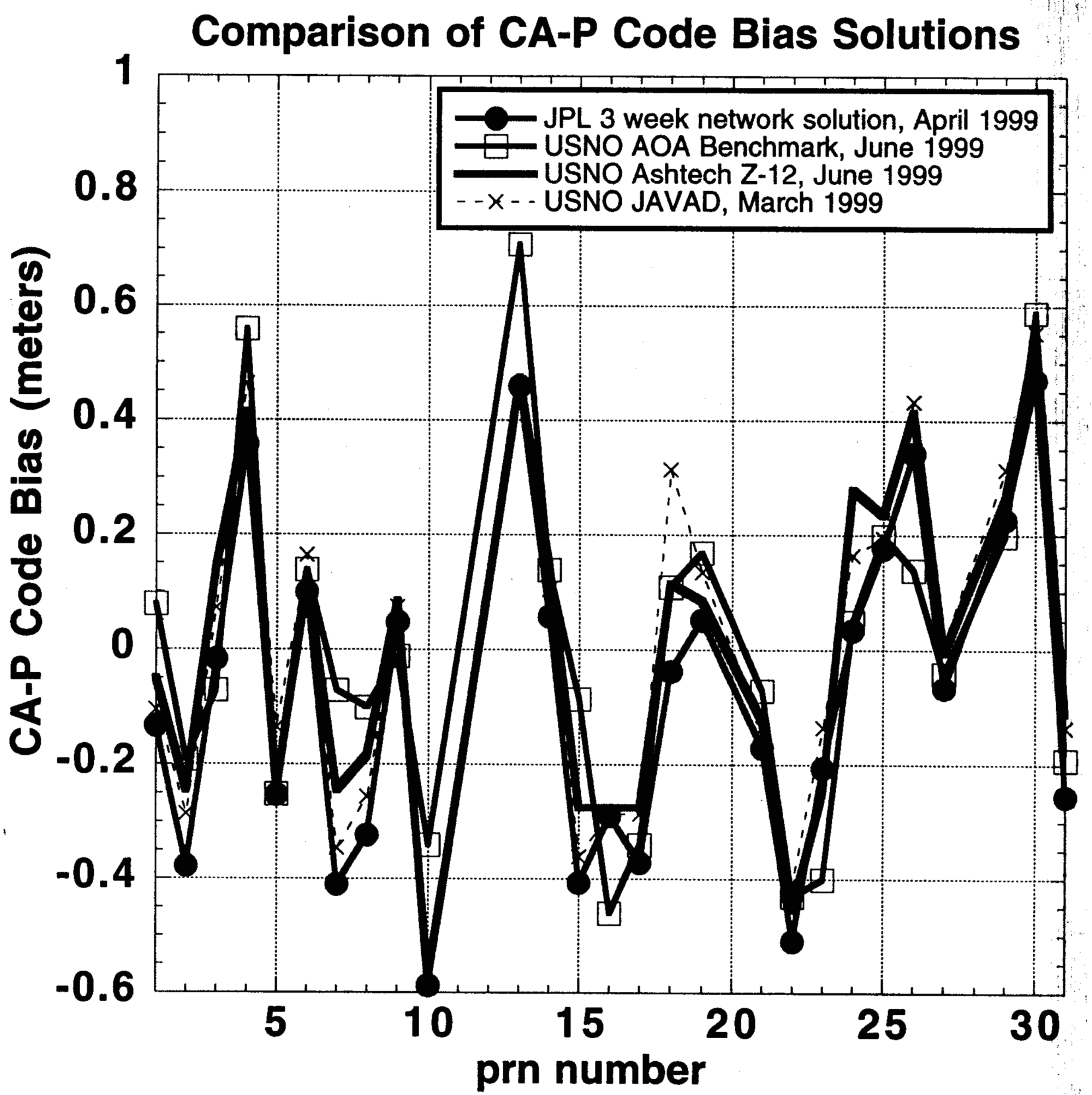
the rms. is an rms. over all prns, not just the ones listed above.

Solving for the CA-P Biases

- JPL has monitored these bias intermittently since 1997 with a network of 14 Ashtech Z-12 receivers in real-time.
  - At hourly increments, a new network solution of the CA-P bias solutions is computed, and the results averaged over several week periods.
  - variations about 4-5 cm over epoch periods.
    - prn 7 changed 20 cm between 12/22/97 and 4/12/98.

Solving for the CA-P Biases

- Independent data analysis contributed by the USNO's Time Service department of data taken from an experimental JAVAD receiver, two NIMA Ashtech Z-12s (all in Washington DC), and a AOA Benchmark (at Schriever AFB) confirms the JPL results.



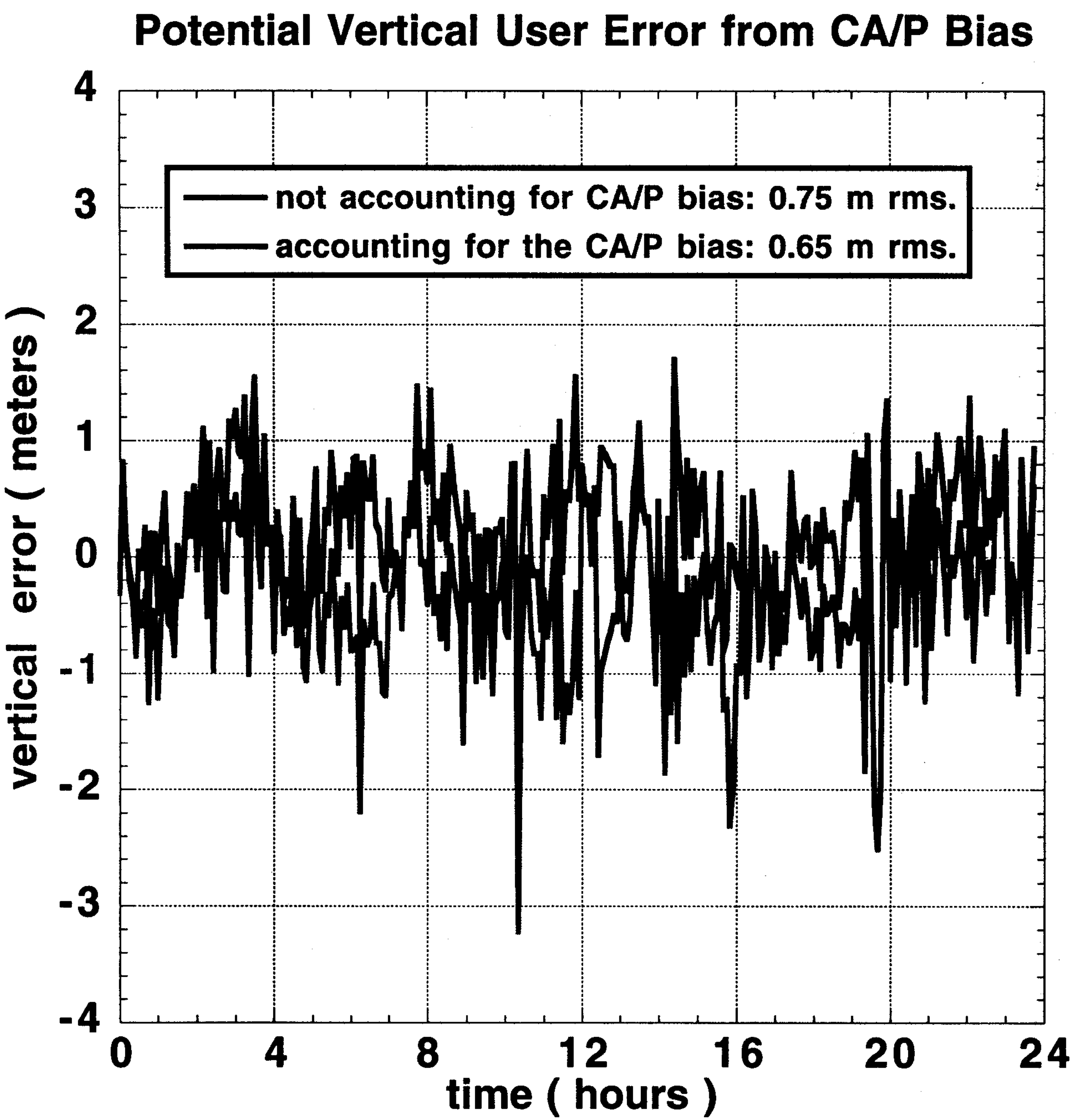
Comparison of CA-P Code Bias Solutions
JPL 3 week network solution, April 1999
USNO AOA Benchmark, June 1999
USNO Ashtech Z-12, June 1999
USNO JAVAD, March 1999
CA-P Code Bias (meters)
prn number
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
5
10
15
20
25
30

Independent Results from USNO Agree with JPL Values

	std. dev. (cm)
JPL - AOA Benchmark	14.4 cm
JPL - Ashtech Z-12	6.3 cm
JPL - JAVAD	6.6 cm

Potential Effect on User Error

- If the user had perfect knowledge of the clocks/orbits/ionosphere/troposphere, what would be effect of ignoring the CA/P bias ?
  - use IGS orbits and IGS CA clocks.
  - use pre-computed zenith troposphere delay for model.
  - use phase only to smooth the multipath in the range data.
  - kinematically position a dual-freq. P code receiver
    - case 1.) account for CA/P code bias
    - case 2.) don't account for CA/P code bias


Potential Vertical User Error from CA/P Bias
not accounting for CA/P bias: 0.75 m rms.
accounting for the CA/P bias: 0.65 m rms.
vertical error (meters)
time (hours)
4
3
2
1
0
-1
-2
-3
-4
0
4
8
12
16
20
24

Summary

- CA/P code bias +/- 50 cm max.
- We think we know it to within 5 cm.
  - based on scatter of hourly results from network solution
- Factor 2.5 less than that of ignoring TauGd.

Summary

- CA/P biases are small but errors for the CA user may become more significant as GPS performance improves.
  - SA-off, better broadcast orbits and clocks
- Other biases will likely exist with the new proposed civilian signals.
  - broadcast a correction for each bias.
  - remove biases with better GPS satellite design.

Appendix

JPL determined CA-P code biases: to convert CA code data to P code data, add CA-P bias values below to the CA range. units are in meters.

1	-0.134	10	-0.588	22	-0.510
2	-0.378	13	0.459	23	-0.206
3	-0.017	14	0.057	24	0.034
4	0.358	15	-0.407	25	0.176
5	-0.253	16	-0.290	26	0.342
6	0.099	17	-0.372	27	-0.067
7	-0.410	18	-0.038	29	0.227
8	-0.324	19	0.051	30	0.470
9	0.047	21	-0.171	31	-0.255